National Aeronautics and Space Administration

UAS Integration in the NAS Project
Part Task 6 V&V Simulation
Primary Results

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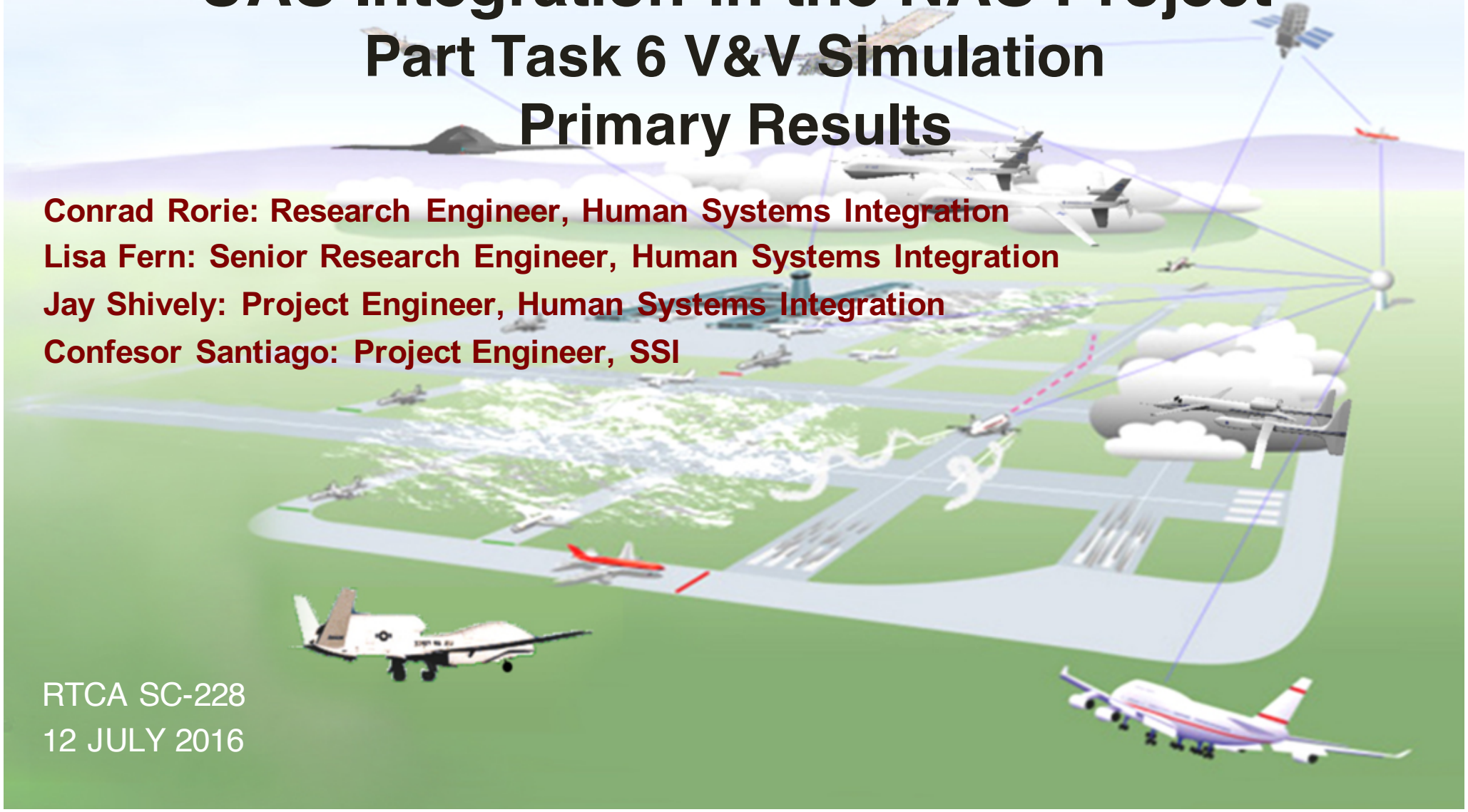


RTCA SC-228
12 JULY 2016

Background

- Purpose:
  - Conduct final V&V activity in support of SC-228 DAA HMI requirements for displays, alerting and guidance
- Goals:
  - Implement the display, alerting and guidance requirements as close as possible in simulation
    - Less emphasis on independent variables
  - Test in representative simulated flight environment
    - E.g., airspace w/ ATC in-the-loop, multiple UAS missions, high-fidelity surveillance models
  - Expected outcome/product(s): pilot performance data to validate final DAA MOPS
    - Losses of Well Clear
    - Pilot response times
    - Additional pilot behavior: TCAS compliance, type/size of maneuvers, ATC coordination
- Overall Research Question:
  - Do we see comparable pilot performance using the minimum display requirements (as currently defined in the draft MOPS) to previous simulations

Background

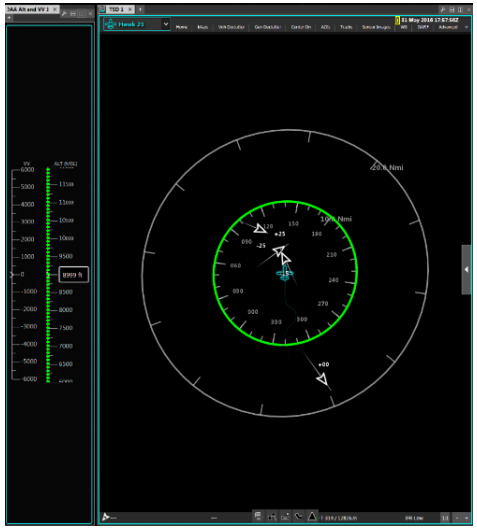
- Changes to expected test set up
  - Planned to run with high fidelity surveillance model for duration of experiment
    - Unable to integrate the model & tune DAA system in time
  - Planned to run with TCAS II for duration of experiment
    - Following first half of data collection, subjective feedback from pilots indicated that they were losing trust in DAA system with repeated TCAS RAs in absence of prior DAA alerting
      - Concerned it impacted how pilots responded to scripted encounters
    - Removed TCAS II from simulation environment for second half of data collection
      - Allowed experimental design to remain balanced

Method: Experimental Design

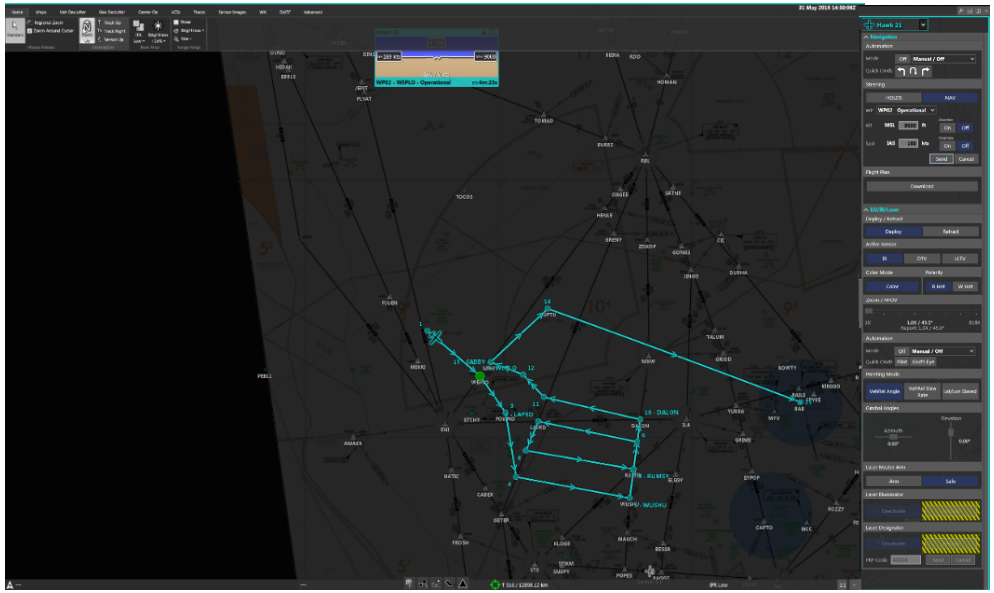
- Experimental Design
  1. Display Configuration (within-subjects)
     1. Standalone DAA display (decoupled from moving map/TSD)
     2. Integrated DAA display (collocated with moving map)
  2. Ownship Equipage (between-subjects)
     1. TCAS II-equipped
     2. No TCAS II
- Participants:
  - 16 active duty UAS pilots
    - Average Age: 49
    - Manned Flying Experience Total Hours: 5000
    - Unmanned Flying Experience Total Hours: 2100

Method: Experimental Design

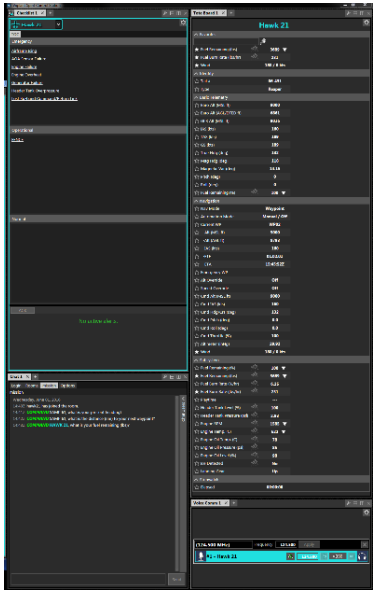
Standalone Configuration



DAA Display



TSD



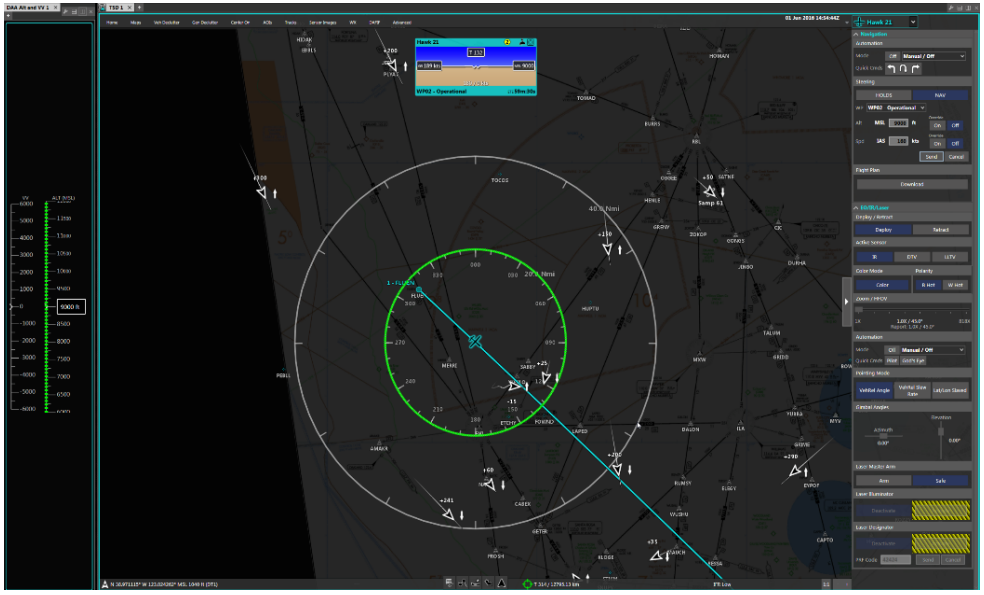
Side Panel

Notes:

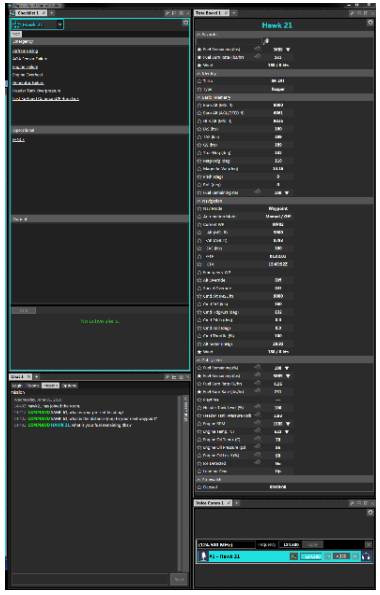
- Pilot could **only make uploads via TSD**; DAA Display only served as a traffic reference
- Pilots trained on how to adjust orientation on both DAA & TSD displays
  - North Up vs. Track Up, and whether orientations matched, was up to pilot discretion

Method: Experimental Design

Integrated Configuration



TSD w/ DAA Display



Side Panel

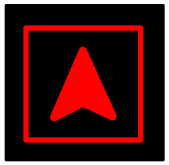
Method: Experimental Design

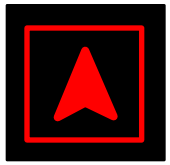
Symbol	Name	Pilot Action	Buffered Well Clear Criteria	Time to Loss of Well Clear	Aural Alert Verbiage
	TCAS RA	• ***Immediate action required*** • Comply with RA sense and vertical rate • Notify ATC as soon as practicable after taking action	*DMOD = 0.55 nmi *ZTHR = 600 ft *modTau = 25 sec	0 sec (+/- 5 sec) (TCPA approximate: 25 sec)	"Climb/Descend"
	DAA Warning Alert	• ***Immediate action required*** • Notify ATC as soon as practicable after taking action	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	25 sec (TCPA approximate: 60 sec)	"Traffic, Maneuver Now" x2
	Corrective DAA Alert	• On current course, ***corrective action required*** • Coordinate with ATC to determine an appropriate maneuver	DMOD = 0.75 nmi HMD = 0.75 nmi ZTHR = 450 ft modTau = 35 sec	55 sec (TCPA approximate: 90 sec)	"Traffic, Avoid"
	Preventive DAA Alert	• On current course, corrective action **should not be required** • Monitor for intruder course changes • Talk with ATC if desired	DMOD = 0.75 nmi HMD = 1.0 nmi ZTHR = 700 ft modTau = 35 sec	55 sec (TCPA approximate: 90 sec)	"Traffic, Monitor"
	Guidance Traffic	• **No action required** • Traffic generating guidance bands outside of current course	Associated w/ bands outside current course	X	N/A
	None (Target)	• **No action required** • No coordination required	Within surveillance field of regard	X	N/A

* These values show the Protection Volume (**not well clear volume**) at MSL 5000-10000ft (TCAS Sensitivity Level 5)

Method: Experimental Design

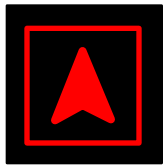
Week 1 – Ownship Equipped with TCAS II

Cooperative Aircraft		
Symbol	Name	Aural Alert Verbiage
	TCAS RA	"Climb/Descend"
	DAA Warning Alert	"Traffic, Maneuver Now" x2
	Corrective DAA Alert	"Traffic, Avoid"
	Preventive DAA Alert	"Traffic, Monitor"
	Guidance Traffic	N/A
	None (Target)	N/A

Non-Cooperative Aircraft		
Symbol	Name	Aural Alert Verbiage
	DAA Warning Alert	"Traffic, Maneuver Now, Traffic" x2
	Corrective DAA Alert	"Traffic, Avoid"
	Preventive DAA Alert	"Traffic, Monitor"
	Guidance Traffic	N/A
	None (Target)	N/A

Method: Experimental Design

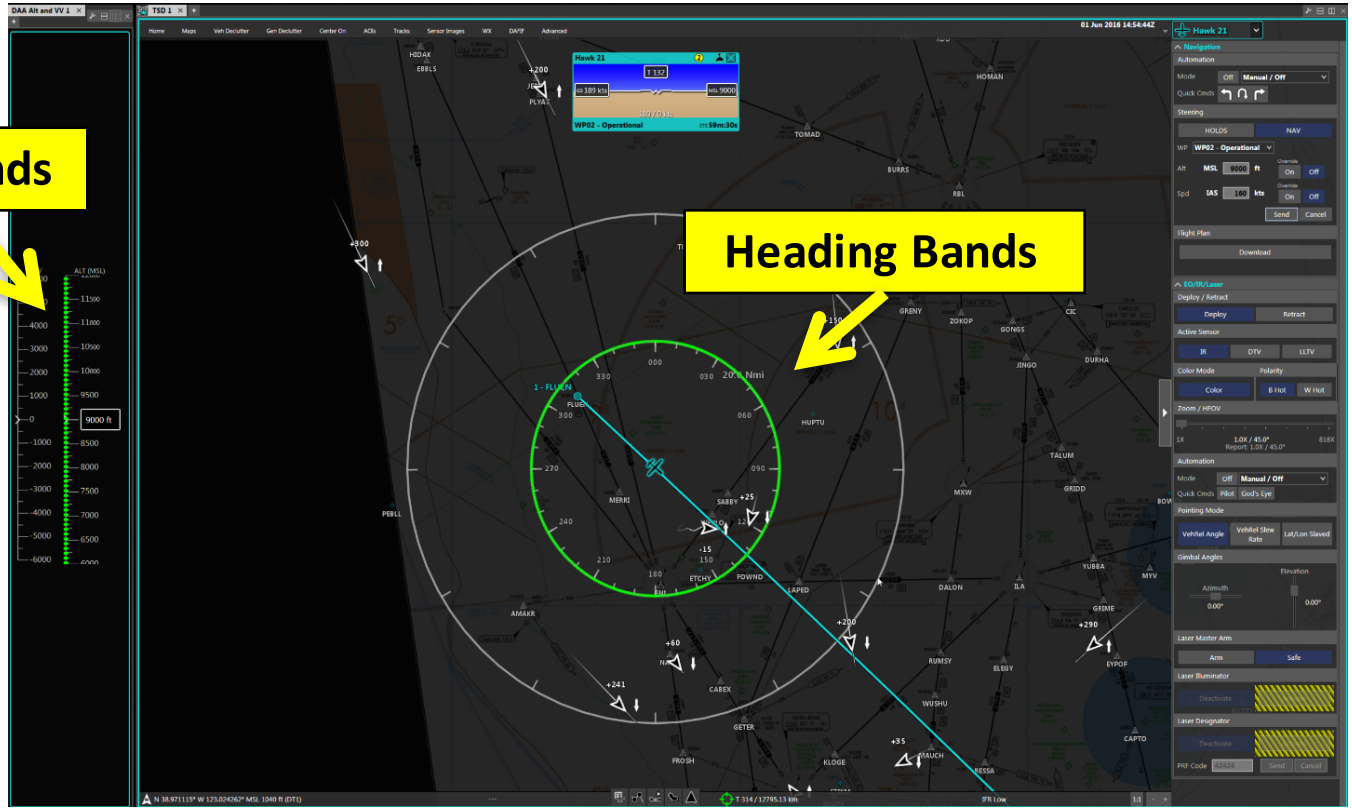
Week 2 – Ownship *Not* Equipped with TCAS II

Cooperative Aircraft		
Symbol	Name	Aural Alert Verbiage
	DAA Warning Alert	"Traffic, Maneuver Now, Traffic" x2
	Corrective DAA Alert	"Traffic, Avoid"
	Preventive DAA Alert	"Traffic, Monitor"
	Guidance Traffic	N/A
	None (Target)	N/A

Non-Cooperative Aircraft		
Symbol	Name	Aural Alert Verbiage
	DAA Warning Alert	"Traffic, Maneuver Now, Traffic" x2
	Corrective DAA Alert	"Traffic, Avoid"
	Preventive DAA Alert	"Traffic, Monitor"
	Guidance Traffic	N/A
	None (Target)	N/A

Method: DAA Guidance Bands

- The JADEM Omni Bands are a form of suggestive maneuver guidance that display relative threat level of various heading and altitude options
  - Headings ‘bands’ appear on the inner range ring
  - Altitude ‘bands’ appear to the far left of the TSD
- Both bands are updated constantly to reflect the most up-to-date information



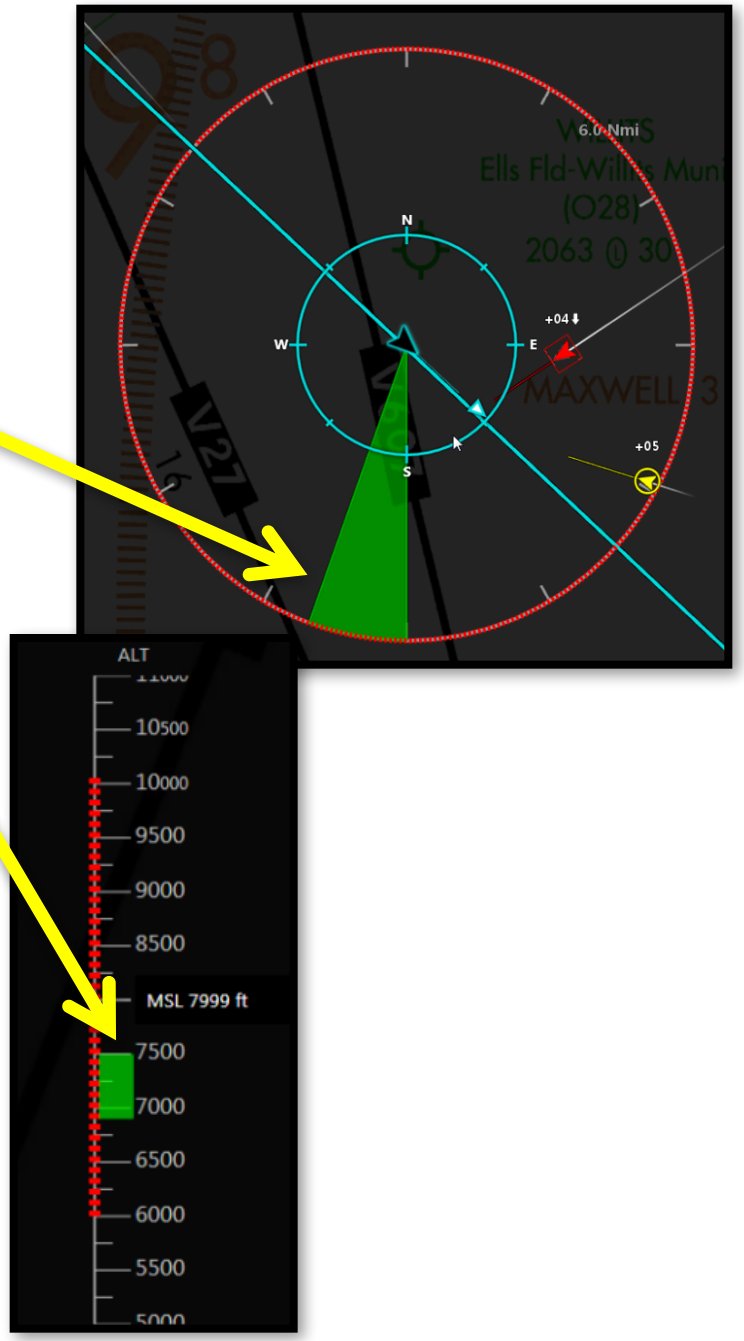
Method: Example DAA Encounter

Method: Well Clear Recovery

- If algorithm determines *horizontal* maneuver will lead to greatest separation:
  - Shown optimal heading region ("wedge") to fly next to ownship

- If algorithm determines *vertical* maneuver will lead to greatest separation:
  - Green altitude block ("wedge") within altitude tape shows optimal altitude range

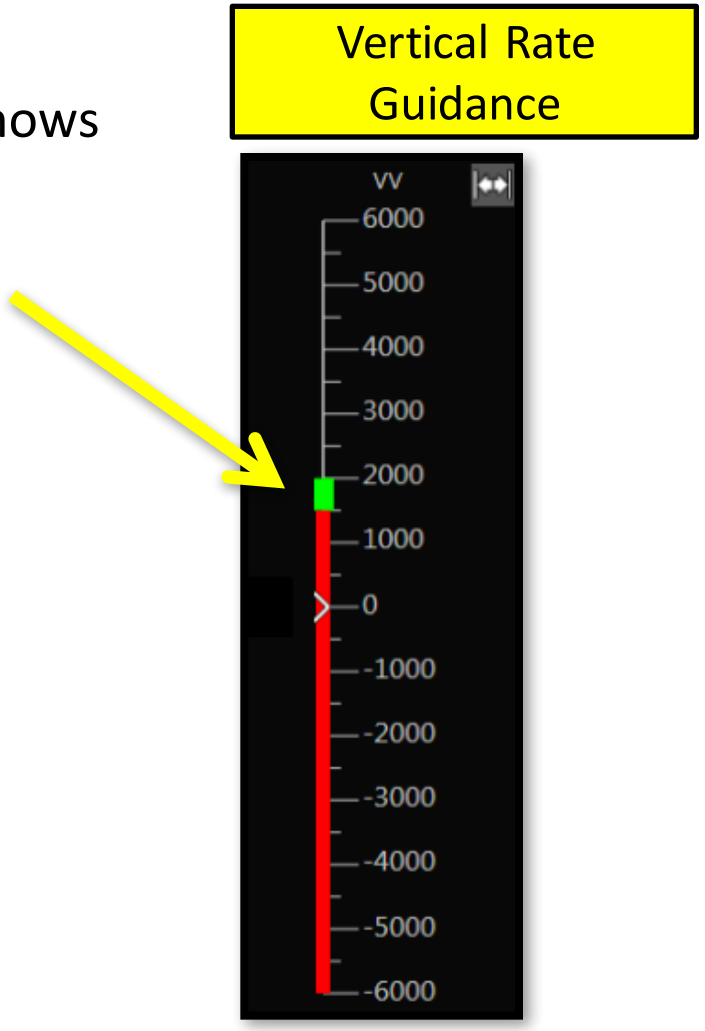
NOTE: No aural alert at this stage



Method: Example WCR Encounter

Method: TCAS II Display

- If TCAS RA is generated:
  - Green band in vertical velocity indicator shows direction and rate of climb to be achieved
- Aural alert generated
  - E.g. “Climb, Climb”



Method: Example TCAS Encounter

Method: Simulation Environment

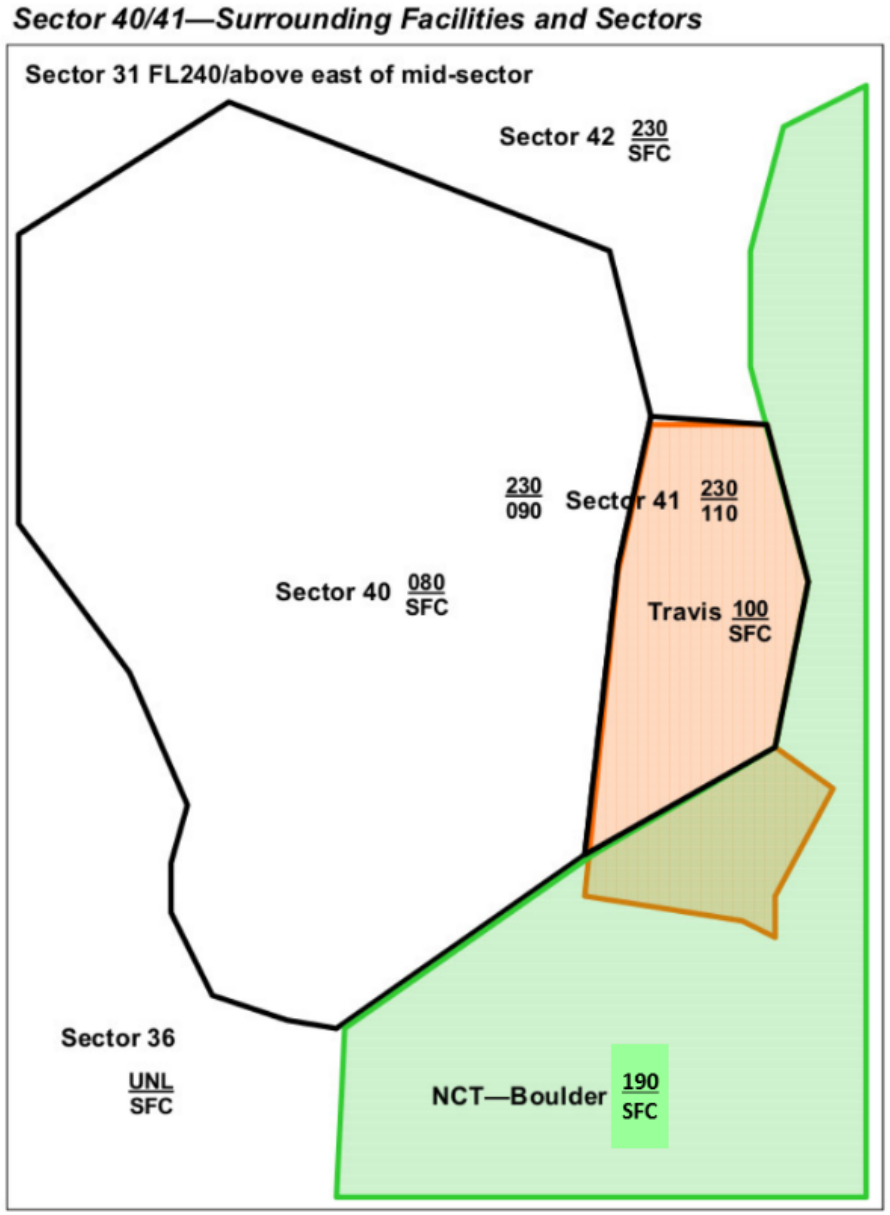
- Task:
  - Fly simulated MQ-9 through Class E airspace (Oakland Center – ZOA 40/41)
    - Navigate along pre-filed routes (used AFRL's Vigilant Spirit Control Station)
      - 2 different routes flown
    - Maintain well clear
    - Coordinate with ATC (time permitting)
    - Attend to secondary tasks (e.g., chat messages, system alerts)
- Pre-planned conflicts with ownship
  - 6 scripted encounters predicted to lose well clear
    - 1/2 with cooperative traffic
    - 1/2 with non-cooperative traffic
  - 2 scripted encounters predicted to become preventive self separation alerts

Method: Simulation Environment

- Simulation Hardware/Software:
  - Vigilant Spirit Control Station (VSCS) from AFRL
    - Standalone & integrated DAA configurations
    - Integrated TCAS II RA alerts and guidance
    - Internal traffic generation tool used for approx. 70% of encounters
  - TCAS II v 7.0 logic (with 7.1 aural alerts) [*when enabled*]
  - JADEM v5.6.7.1 DAA System
    - DAA alerting
    - DAA guidance (Omni Bands)
    - Well Clear Recovery guidance
    - Perfect surveillance data (no uncertainty models applied)

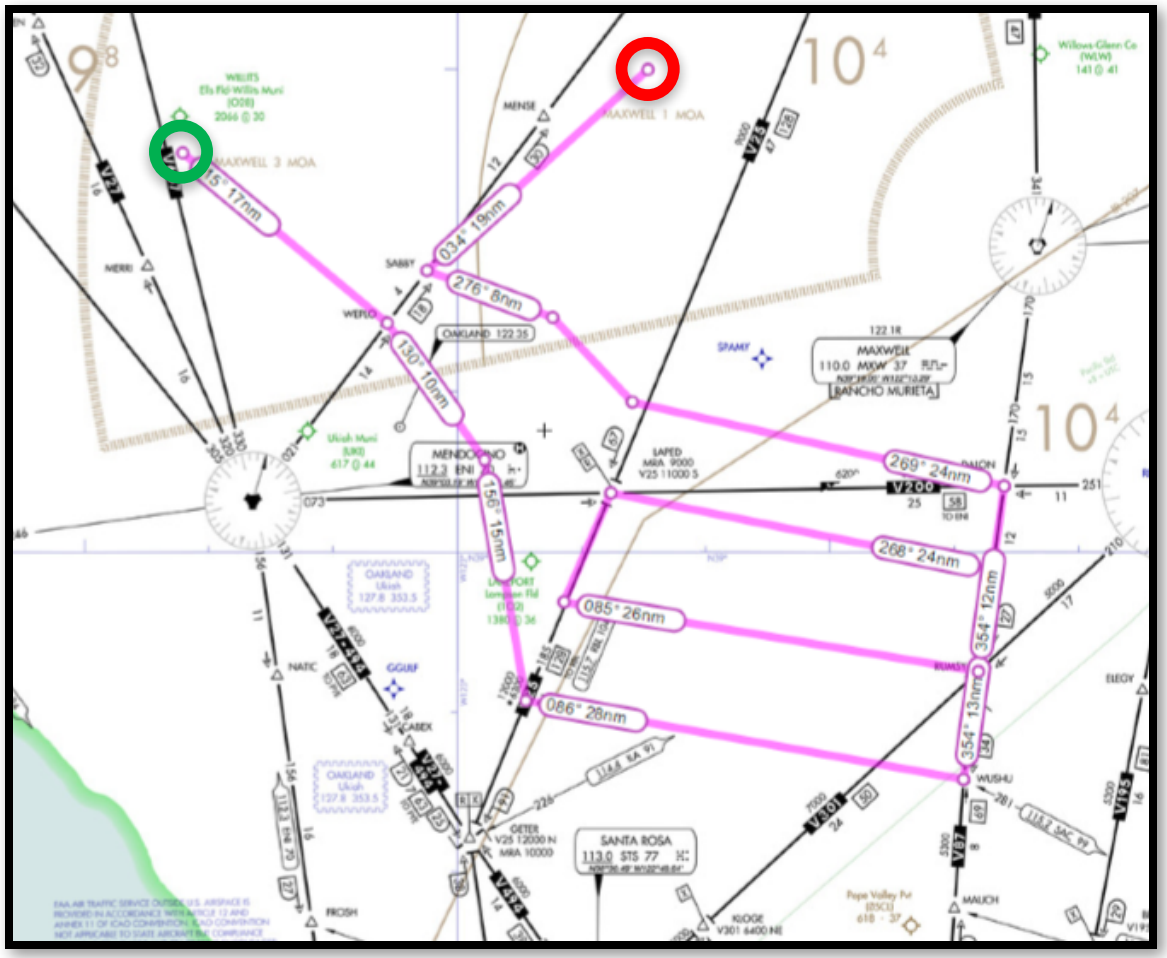
Method: Simulation Environment

- Mission routes located within Oakland Center (ZOA40/41)
  - Both mission routes flown simultaneously
    - 2 UAS being flown from separate GCS
  - Includes a variety of classes of airspace
    - IFR traffic into and out of SFO and OAK
    - VFR traffic from smaller airports (e.g., STS and APC)



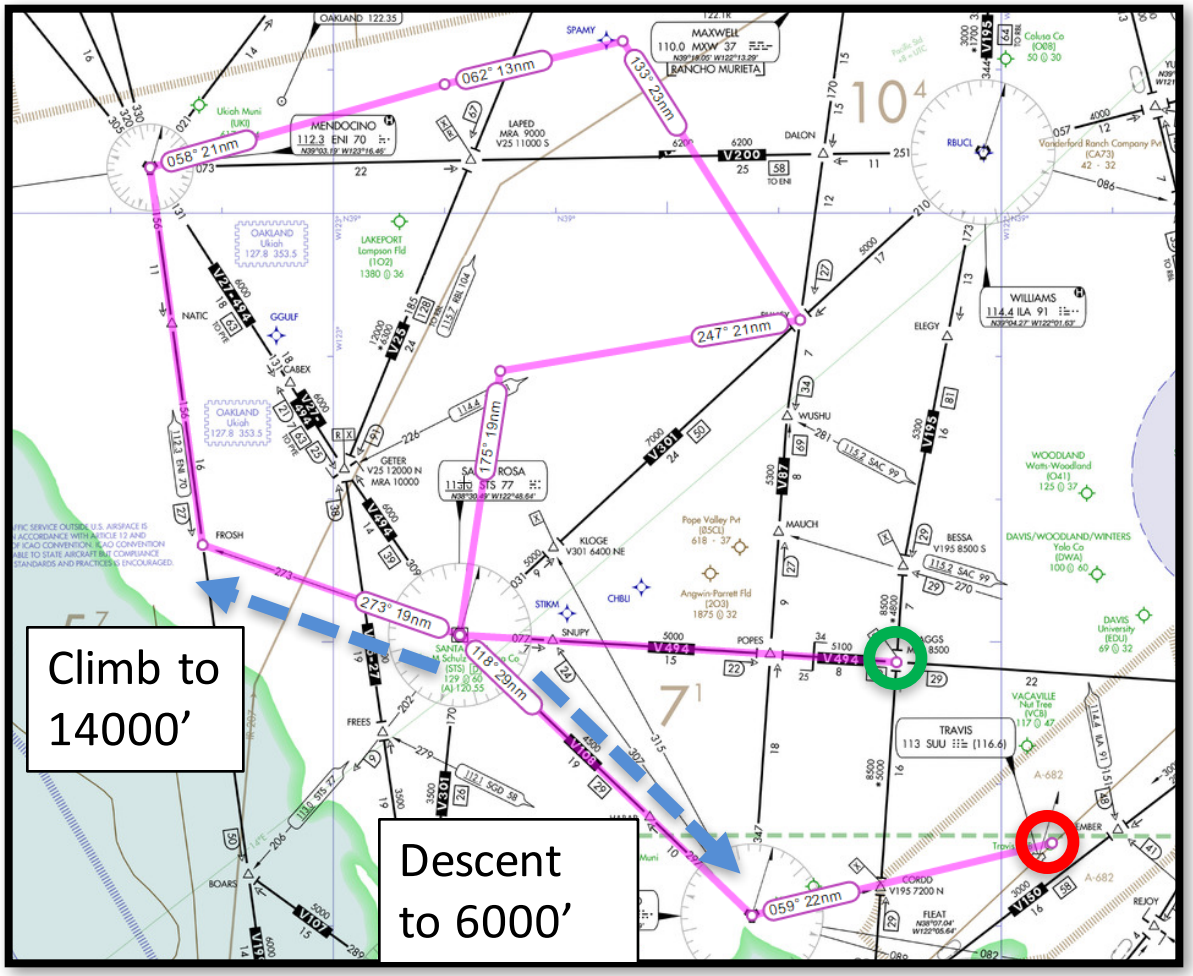
Method: Simulation Environment

- Fire Line Track (HAWK21)
  - Level at 9000’
  - Serving as air asset for California Department of Forestry for fire burning north of Clear Lake



Method: Simulation Environment

- Air Sampling Track (SAMP61)
  - Starts at 10000’, contains climb & descent
  - Serving as air asset for California Air Resources Board to measure quality of air east of Santa Rosa



Method: Simulation Environment

- Simulation confederates
  - NATCA controller managed UAS and manned traffic within ZOA 40/41
    - Simulated manned traffic based on actual sector activity
  - Pseudo-pilots managed all manned traffic to provide dynamic sector activity
  - ATC SME operated as 'ghost' controller to ensure conflicts were generated
  - HSI researcher operated VSCS internal conflict generator

Key Research Questions

- Loss of Well Clear
  - Did display configuration impact rate or severity of LoWC?
  - Any other observable factors for instances of LoWC?
- Response Time
  - Did display configuration impact how quickly pilots were able to perform the DAA task?
    - If so, which component of the DAA task did display configuration have an effect on?
  - Did any other factors impact pilot response time (e.g., trial, mission type, ownship equipage, intruder equipage)?

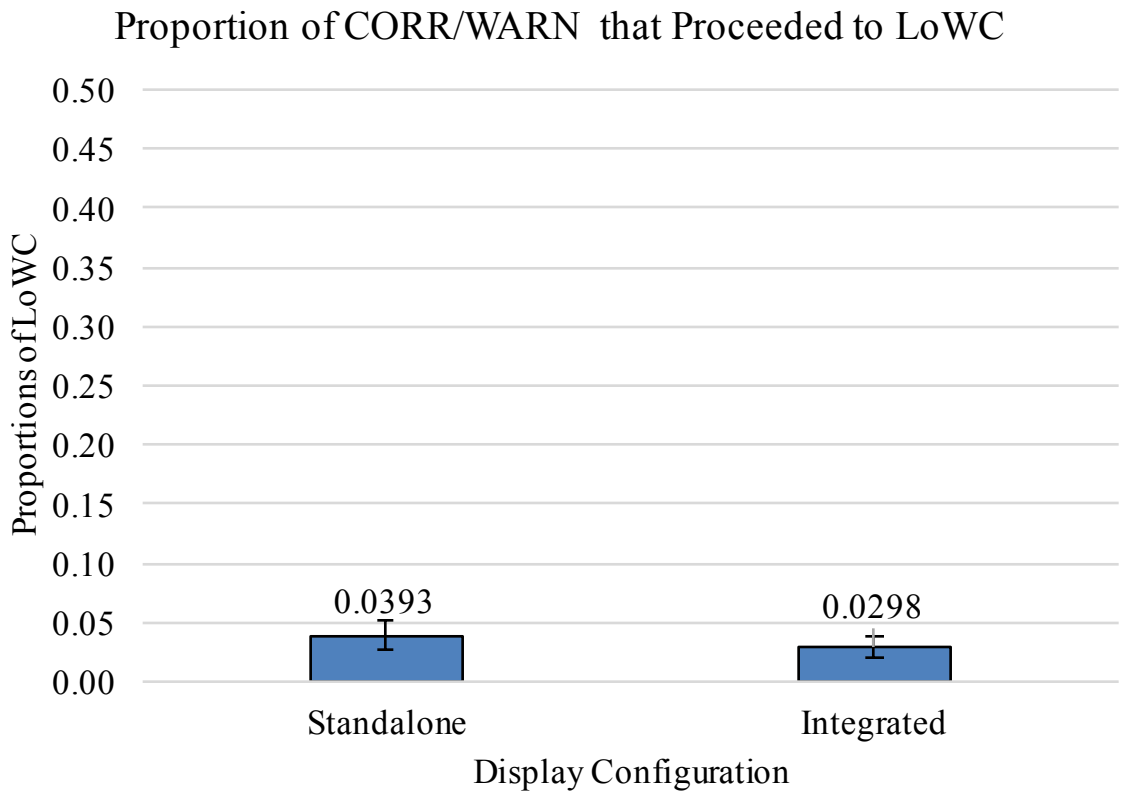
Key Research Questions

- TCAS II RA Metrics
  - Number of RAs issued
  - Pilot response time to RAs and rate of compliance
  - How often were pilots 'well clear' when an RA was issued?
    - Did presence of TCAS II degrade pilot performance or understanding of the DAA system?
- Additional Pilot Metrics
  - ATC coordination
    - How often did pilots gain approval prior to maneuvering away from, or back to, their mission route?
  - Maneuver Statistics
    - Did pilots overwhelmingly prefer certain types of maneuvers?
      - Did any variable (e.g., display configuration) impact how they maneuvered?
    - Did size of maneuvers vary between conditions?

LOSS OF WELL CLEAR

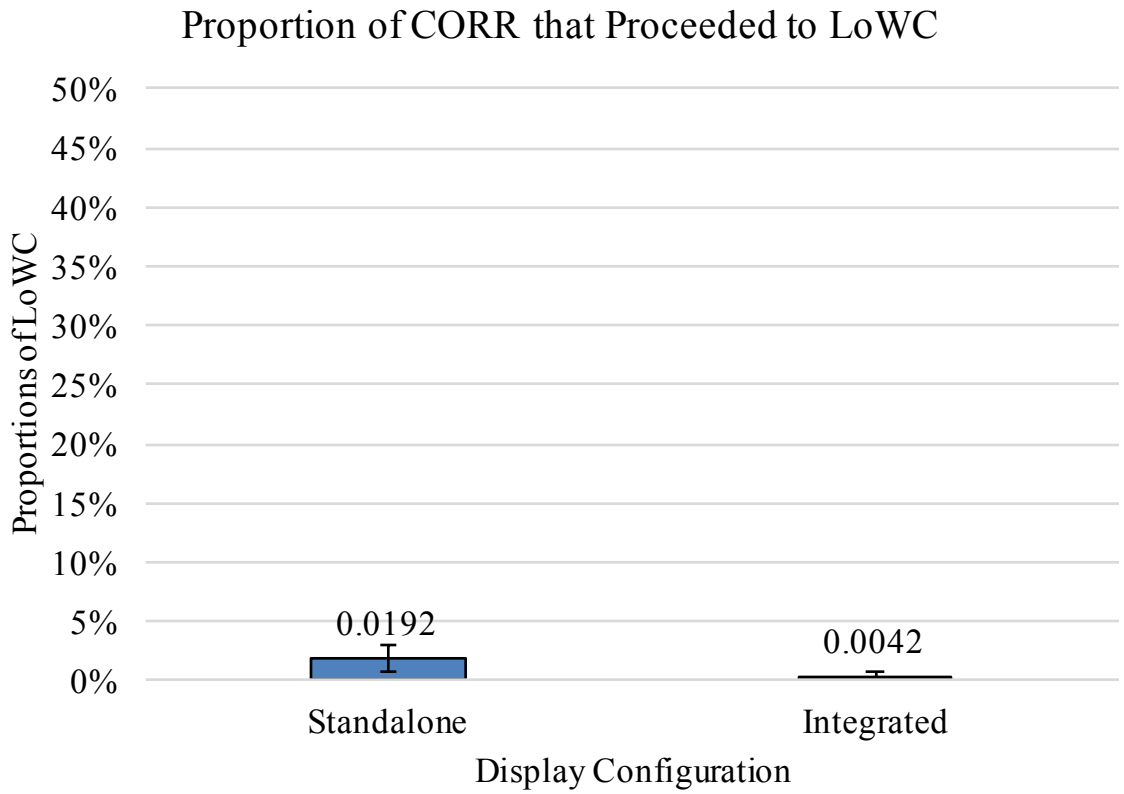
Loss of Well Clear Proportions

- 16 total LoWC (out of 466 encounters) with encounters that appeared as a Corrective or Warning at First Alert
  - Standalone = 9 total LoWC; Integrated = 7 total LoWC



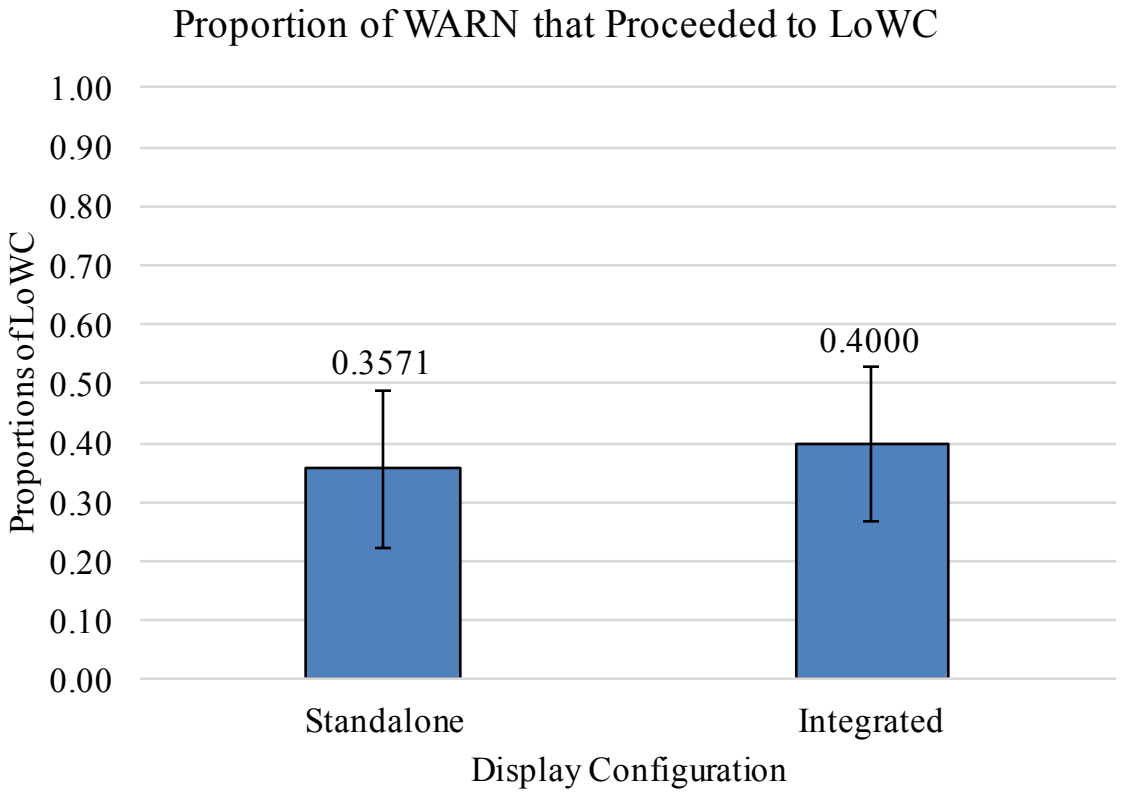
Loss of Well Clear Proportions

- 5 LoWC (out of 436 encounters) with encounters that appeared as a Corrective at First Alert (dropping those that started as Warning)
  - Standalone = 4 LoWC; Integrated = 1 LoWC



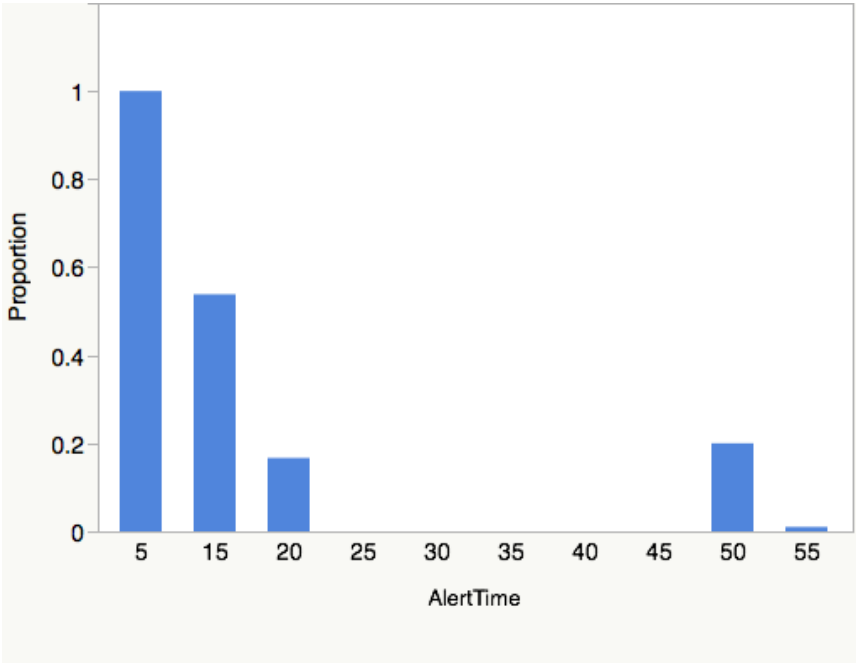
Loss of Well Clear Proportions

- 11 LoWC (out of 30 encounters) with encounters that appeared as a Warning at First Alert (dropping those that started as Corrective)
  - 29 of these were from single encounter, which was scripted to make 90deg blunder into ownship to cause immediate DAA Warning
  - Standalone = 5 LoWC; Integrated = 6 LoWC



Diagnosing LoWC

- 11 LoWC when intruder was Warning at First Alert
  - *Insufficient time to respond*
    - 8 LoWC occurred when pilots had less than 15sec to LoWC
  - *Insufficient upload*
    - 2 LoWC where pilot uploaded an altitude despite bands showing all red
    - 1 LoWC where pilot was too slow making upload



Diagnosing LoWC

- 5 LoWC when intruder was Corrective at First Alert
  - *Display Configuration*
    - Standalone (4 LoWC)
      - 1 pilot made multiple ineffective maneuvers, likely compounded by fact that the DAA display was in different orientation than TSD
      - 2 pilots made ineffective heading changes, likely compounded by the fact that the bands did not coincide with control interfaces
      - 1 pilot failed to notice altitude bands were no longer clear by time upload was made
    - Integrated (1 LoWC)
      - 1 pilot failed to notice altitude bands were no longer clear by time upload was made
  - *Trial* (4 LoWC)
    - 4 occurred during first trial of the day

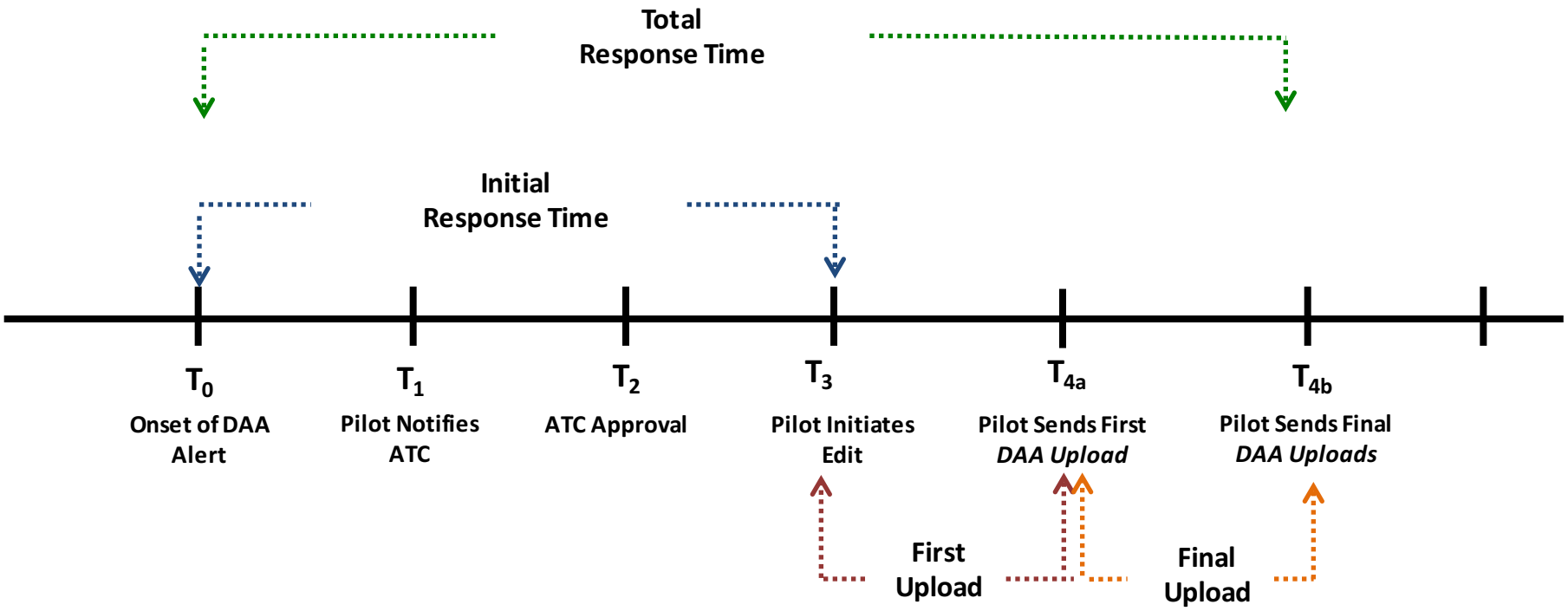
LoWC Example

- Case of DAA display & TSD having different orientations

RESPONSE TIME DATA

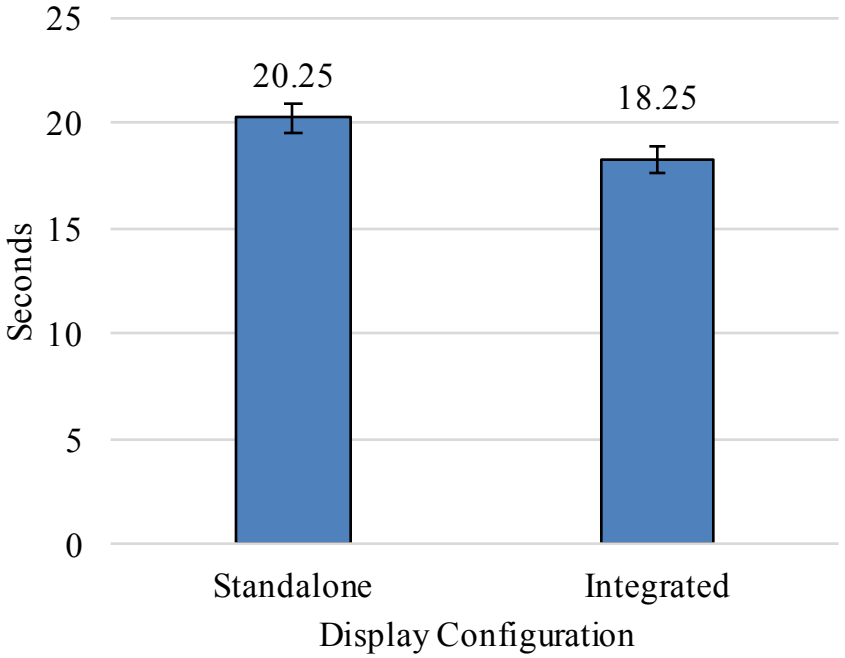
Metrics

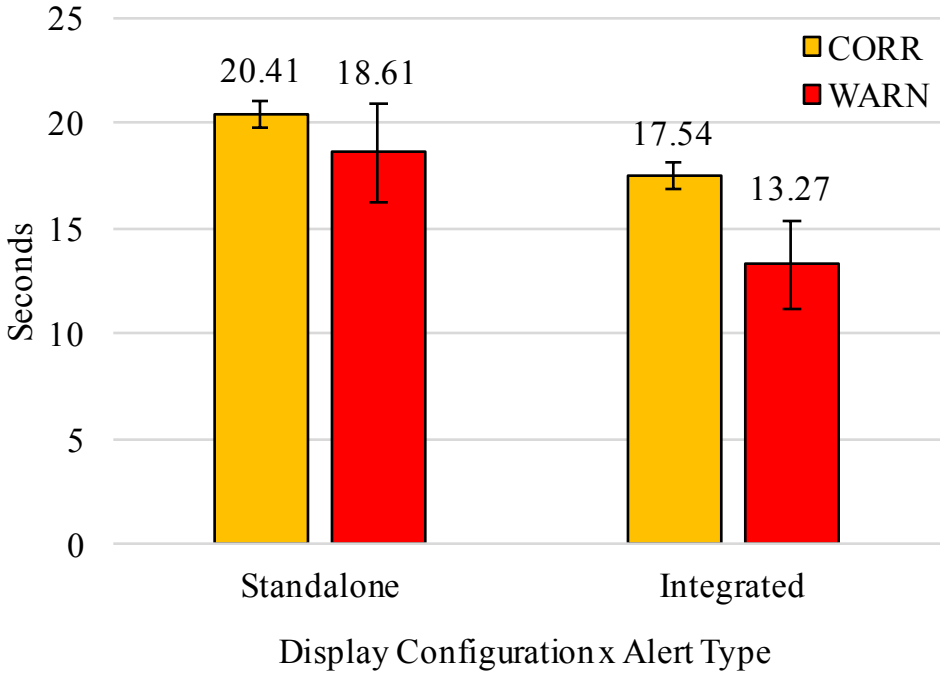
- Primary response time metric is Total Response time
  - Comprised of Initial Response Time, Initial Edit Time and Total Edit Time



Total Response Time

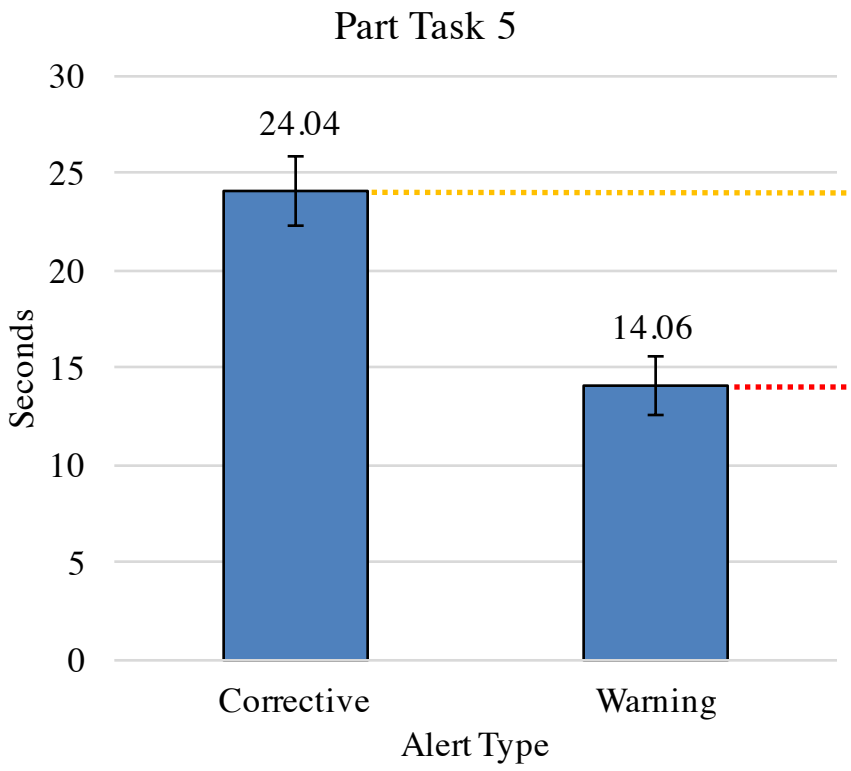
- Pilots sent final upload to their aircraft **2 sec faster** (~10%) in *Integrated* display configuration (not statistically different ($p > .05$))
- More pronounced difference between displays when separated by alert level
  - Pilots sent final upload **5.5 sec faster** (~30%) in response to DAA Warning alerts in Integrated display configuration
    - No statistical difference (large variability, a result of small sample size)

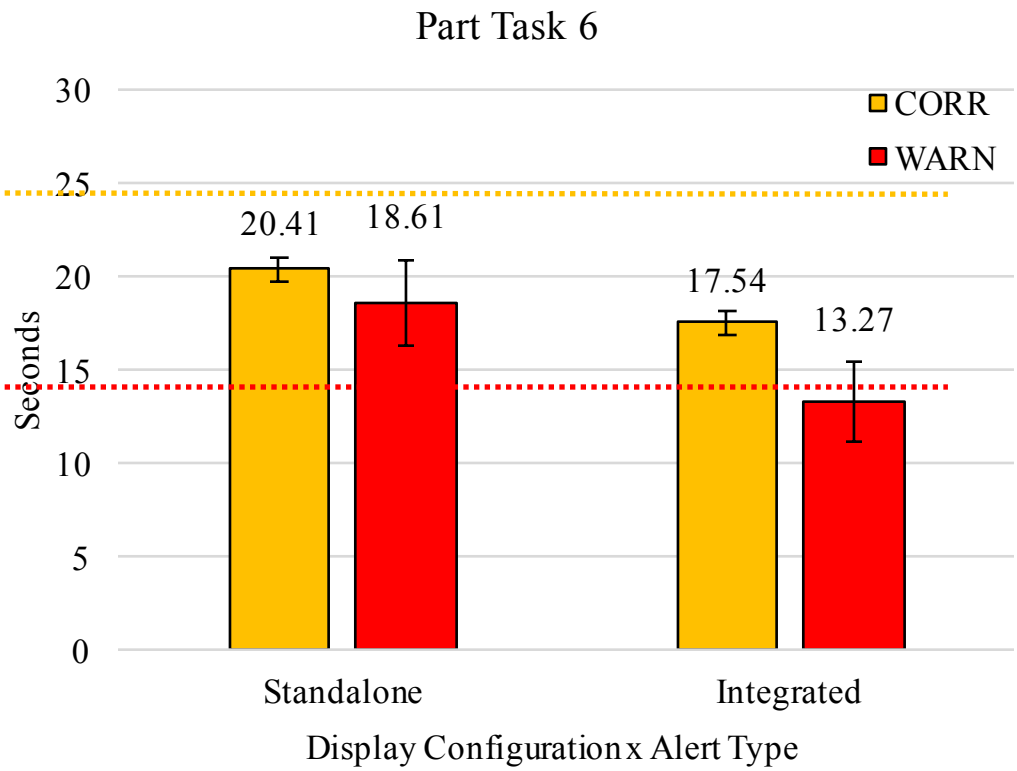




Total Response Time

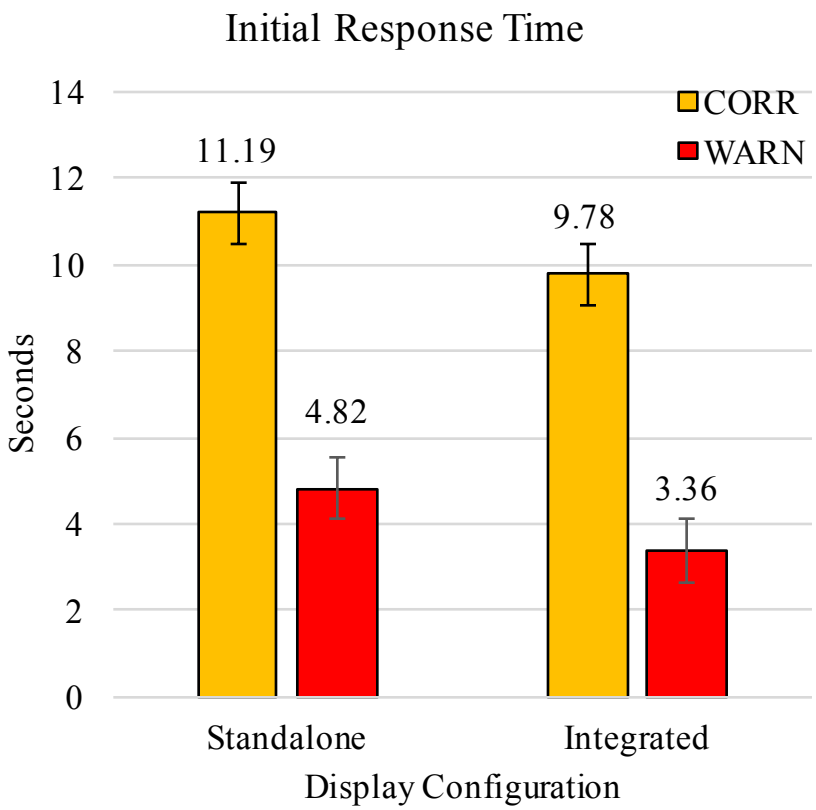
- Compared to Part Task 5, times are generally faster in PT6, with exception of pilot responses to DAA Warnings in the Standalone condition

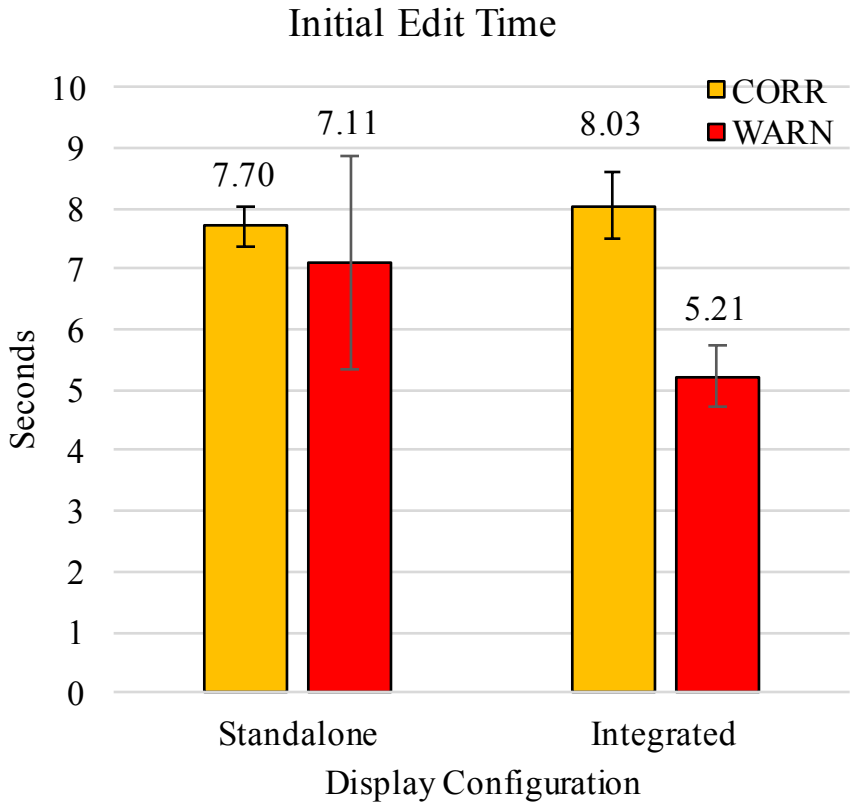




Initial Response and Initial Edit (First Upload)

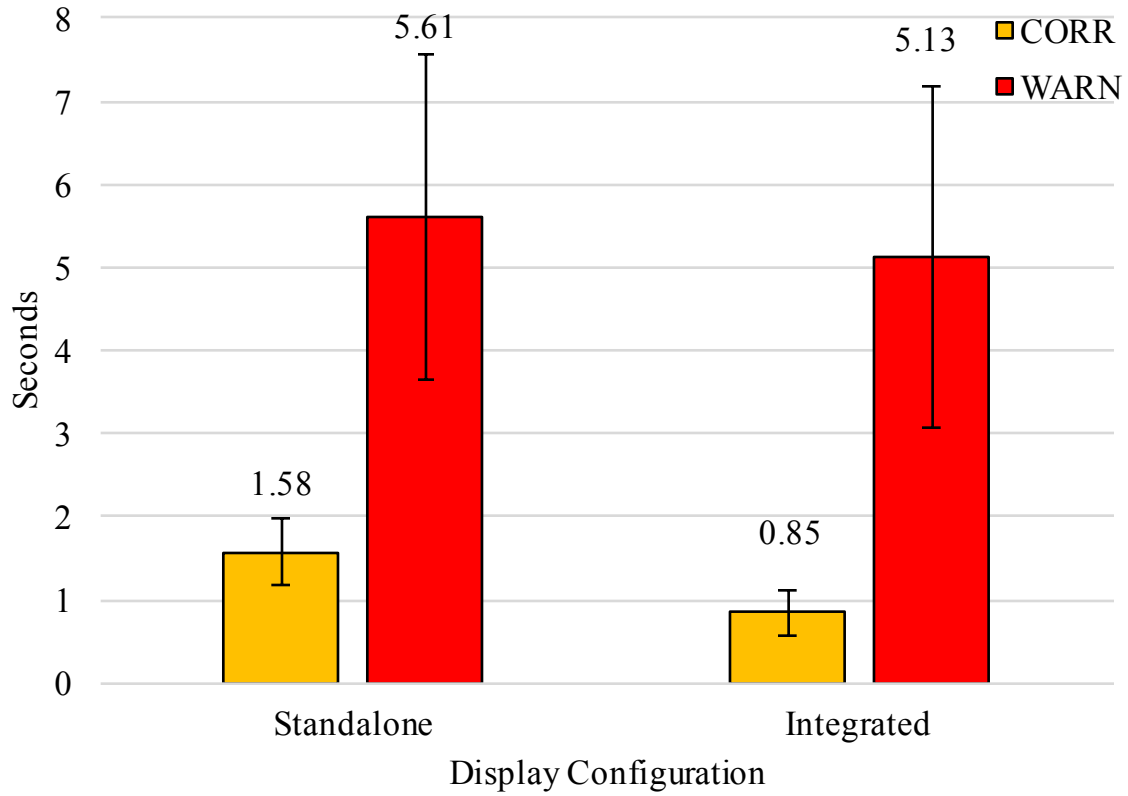
- Bulk of the reduction in total response times for Warning alerts is that pilots initiate their response much earlier
  - To a lesser extent, pilots also spend less time implementing their edits





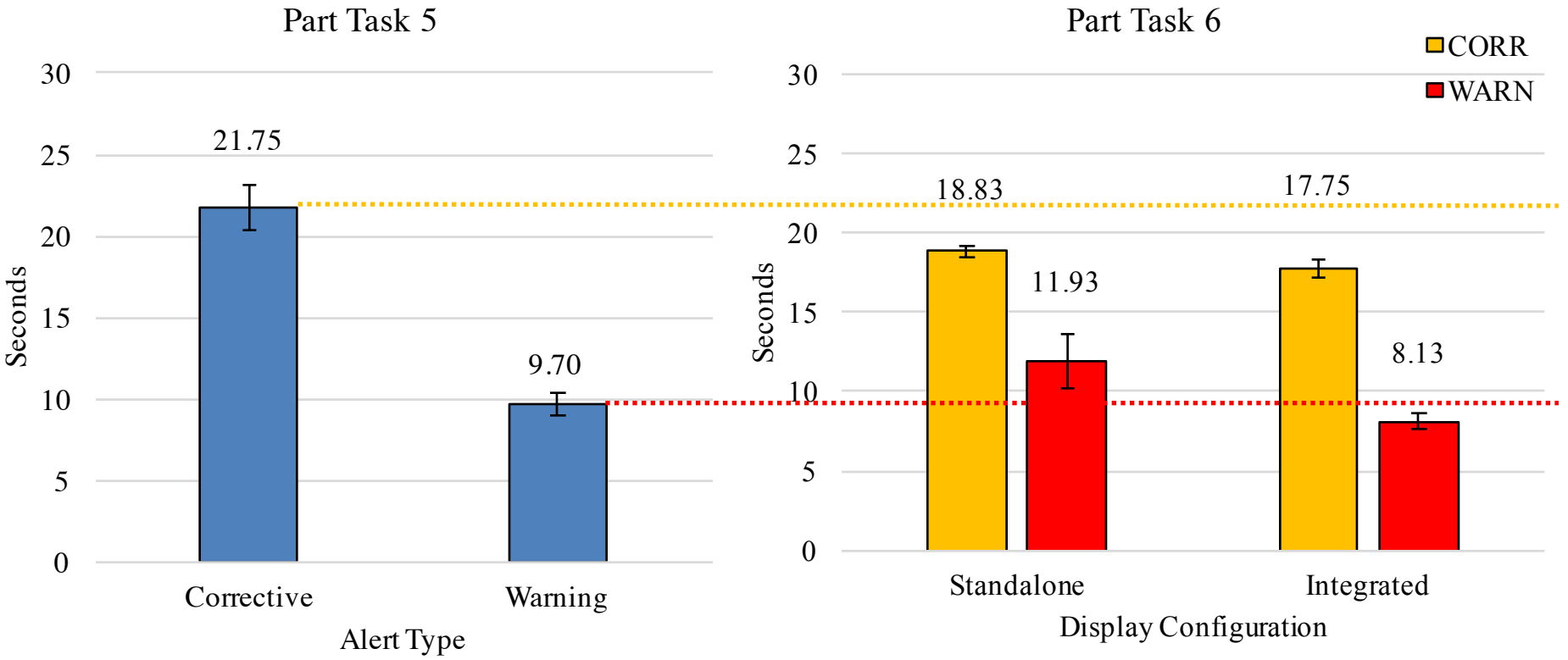
Subsequent Edits (Additional Uploads)

- Complicating things was the fact that pilots often sent a late upload in response to well clear recovery, leading to larger *total* edit times for Warnings than for Correctives



Aircraft Response Time

- If you only consider first upload, as opposed to final upload as used by total response time, we see response times more in line with expectations
  - Comparison to PT5 is cleaner, although response to Warning in Standalone configuration is still slower in PT6



Key Research Questions

- TCAS II Research Questions:
  - Under nominal conditions, how many encounters progress to a corrective RA?
  - What is the relative average response time for pilots responding to a corrective RA?
    - How does it compare to response times to corrective and warning alerts?
  - What is the compliance rate to corrective RAs?
  - Were there instances of near mid air collisions (NMACs)?

Conclusions

- Saw expected pilot performance with previous simulations using minimum display, alerting & guidance requirements
  - LoWC metrics & pilot response times
- Standalone display resulted in little to no performance differences compared to the Integrated display configuration
  - Slightly longer pilot response times (expected)
  - While Standalone display led to more LoWC against threats that were Corrective at First Alert, this almost always happened in first trial of the day
    - Fact that Integrated configuration only had a single LoWC suggests pilots may need more time or training on Standalone displays than on Integrated
- Additional observations
  - Altitude tape needs to be on right side DAA display (frequently disregarded) and as close to the center of their field of view as possible
    - In both the Standalone and Integrated conditions pilots uploaded a vertical maneuver that was no longer conflict-free according to DAA altitude bands
  - Excessive TCAS RAs while well clear impact pilots' trust of DAA alert structure
  - Longer run times (1 hr vs. 38 min) saw some fatigue effect
    - Initial response times went up in trial 4 compared to first 3 trials of the day
    - Didn't seem to impact overall performance